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a. Number of Papers Submitted to Refereed Journal but not yet published: 1

b. Number of Papers Published in Refereed Journals: 1
(list attached)

c. Number of Books or Chapters Submitted but not yet Published: 0

d. Number of Books or Chapters Published: 0 (list attached)

e. Number of Printed Technical Reports & Non-Refereed Papers: 6
(list attached)

f. Number of Patents Filed: 0

g. Number of Patents Granted: 0 (list attached)

h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 0

i. Number of Presentations at Workshops or Prof. Society Meetings: 3

j. Honors/Awards/Prizes for Contract/Grant Employees: NONE
(list attached, this might include Scientific Soc. Awards/ Offices, Promotions/Faculty Awards/Offices, etc.)

k. Total number of Graduate Students and Post-Docs Supported at least 25% this year on this contract/grant:

Grad Students 5 and Post-Docs 1 including
Grad Student Female 0 and Post-Docs Female 0
Grad Student Minority 1 and Post-Doc Minority 0

Minorities include Blacks, Aleuts, AmIndians, Hispanics, etc.
NB: Asians are not considered an under-represented or minority group in science and engineering.

Enclosure (3)

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SAR-Related Stress Variability in the Marine Atmospheric Boundary Layer (MABL) (HIGH-RES ARI)

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PROJECT ABSTRACT

By variably stressing the sea surface, secondary circulations within the marine atmospheric boundary layer (MABL) can modulate the sea–surface wave field and so can produce discernible signatures on SAR images of the ocean. Indeed, at the Fall '93 ARI workshop, Robert Beal showed ERS-I images illustrating the ubiquity of these signatures during the second HIGH-RES cruise in June 1993. Among the resulting signatures, the quasi-linear and cellular microscale patterns still require adequate explanation. The ubiquitous MABL two- and three-dimensional convective circulations provide promising candidates for the forcing phenomena producing these signatures. These microscale circulations have horizontal wavelengths on the order of one to ten times the boundary layer depth, or approximately one to ten km, and temporal scales on the order of one to ten hours. Thus, they produce stress variations on the spatial and temporal scales of the quasi-linear and cellular SAR signatures. Similarly the frequent occurrence of two-dimensional mesoscale atmospheric circulations in response to the SST gradient along the northwest wall of the Gulf Stream adds an atmospheric component to Gulf Stream signatures on SAR images on cross–stream scales of 1 to 50 km.

Long Term Goals:

Our ultimate goal is to develop methods for diagnosing both the form and the effect on sea-surface stress patterns of buoyantly-forced MABL flows given only values of the large-scale meteorological and oceanographic parameters. As briefly summarized below, we continue to make strong progress on this problem using several interacting, complementary techniques that range from data analysis to model development.

Near Term Objectives:

Our most immediate goal is to determine how effective these two- and three-dimensional buoyantly forced MABL circulations, which have scales on the order of 0.1 to 50 km, are in producing patterns of sea-surface stress variability that can be directly linked to the quasi-linear and cellular SAR signatures that were observed during the HIGH-RES ARI experiment and by earlier, satellite mounted, sensors. Two primary objectives must be met for us to achieve these goals. First, the surface layer structure within the MABL must be related to the sea-surface stress patterns for the solenoidal MABL circulation associated with quasi-linear sea-surface temperature (SST) gradients and for each of the three microscale atmospheric boundary layer convective forms: the two-dimensional mixed-layer rolls, the three-dimensional mixed-layer thermals, and the surface layer plumes. Second, the environmental conditions necessary and sufficient for the formation of each of these buoyantly-driven circulations must be identified.

Approach:

The convective component of the first objective has been completed as the MS thesis of Todd Sikora (Sikora 1992; Sikora and Young 1993, 1994) by using both conditional sampling and composite analysis of atmospheric surface layer observations to describe the occurrence, structure, and sea-surface stress and wind patterns of MABL convection. Aircraft data from the marine stratocumulus-topped boundary layers observed during Project FIRE [First ISSCP (International Satellite Cloud Climatology Program) Regional Experiment] were used for the data analysis. Conditional sampling of these boundary-layer data identified updrafts and downdrafts, while composite analysis was used to summarize the spatial (planview) variations within updrafts and downdrafts to quantify the average structure of each. Current work focuses on collaboration with the wave and backscatter modelers of the HIGH-RES ARI to provide them with appropriately scaled forcing fields for simulation of the "mottled" signatures of three-dimensional convection seen so commonly over the Gulf Stream on the ERS-I overpasses during the second HIGH-RES cruise. This task will be followed by a comparison of these observational results with output from the two new, intermediate-order MABL convection models described below. Results of these models will also be made available to our HIGH-RES collaborators in a form suitable for forcing their wave models.

With the observational analysis of microscale convection completed, we are deeply involved in the next MABL phenomenon of interest to the HIGH-RES ARI community: the MABL solenoidal circulation associated with the sharp SST gradient along the northwest wall of the Gulf Stream. Observations from the two ARI cruises are being used to create similar composite analyses of this somewhat larger scale, yet still buoyantly driven, flow. The ship-based sensors deployed during both cruises by Penn State and collaborators from Wood's Hole Oceanographic Institution will permit measurements of this MABL response to

the ocean front as well as the resulting feedback to the wave field via cross-front variations in the wind and stress. Cross-front sampling legs and along-front legs with two ships paired across the front have yielded maximum information on the role of the SST gradient in forcing the observed horizontal variations of the surface wave field. We have completed the first three-dimensional simulation of this flow using the Penn State/NCAR mesoscale model MM4. Results of these simulations will be made available to HIGH-RES colleagues as time-dependent two-dimensional forcing fields for models of both the background wave field and for simulation of the SAR signatures of this Gulf Stream atmospheric front.

Elucidation of the stress variability expected in different forcing regimes is being achieved by the development and study of new two-dimensional and three-dimensional intermediate-order spectral models of MABL convection. The first, which extends the boundary layer roll study of Haack and Shirer (1992), is a two-dimensional model that is the MS thesis project for Peter Bromfield. The second is a three-dimensional convection model whose development was begun by Julie Schramm and is being continued by MS students Louis Zuccarello and Bruce Lambert. In both these models, the boundary conditions are based on boundary layer similarity theory and so are sufficiently general that the surface stress can be nonzero. Lastly, in work begun under funding by the National Science Foundation and continued here, PhD student Mark Laufersweiler completed a study of stratocumulus circulations (Laufersweiler 1993); in some circumstances two possible boundary layer responses may occur for the same forcing.

To help guide comparison of observed and modeled results, algorithms for adequately estimating such chaos measures as the correlation dimension are needed as well as a means for estimating the probable errors in these estimates. We have developed such an algorithm (Wells *et al.* 1993, 1994), and MS student Christian Fosmire has applied it to boundary layer wind data (Fosmire 1993). This work is now continuing as part of the MBL ARI.

Recent Tasks Completed:

Preparation of a dynamically-based methodology for converting the planview patterns of surface stress variability caused by MABL convective updrafts and downdrafts into forcing fields for ocean wave and radar backscatter simulations of specific SAR images has been completed, with the results accepted for publication (Sikora and Young 1993, 1994). Collaborations with several HIGH-RES colleagues are underway on the application of this new methodology.

Meteorological observations and infrared satellite images have been acquired for interpretation of an ERS-1 SAR feature in collaboration with HIGH-RES ARI researcher Robert Beal of Johns Hopkins University's Applied Physics Laboratory (APL).

The first of several mesoscale atmospheric simulations of the Gulf Stream atmospheric front for priority days from the first HIGH-RES ARI cruise in Fall 1991 was completed using the Penn State mesoscale model MM4. Analysis routines to diagnose the dynamics of this system and the resulting sea-surface stress field have been prepared by graduate student Sean Sublette.

A preliminary version of the three-dimensional intermediate-order MABL convection model was integrated; initial results showed that the forms of the stress and heat flux profiles were correct and matched those observed in the stratocumulus-topped MABL by Brümmer and Busack (1990). The energy budget properties were not completely correct, however, and appear to be caused in part by an improper handling of the pressure gradient term in the equation of motion. Because this term is much easier to handle in a two-dimensional model, we undertook the development of such a model as the MS thesis project for Peter Bromfield, who is currently completing a linear stability analysis of the nonconvective state to determine the critical forcing values for roll development. We also have reformulated the three-dimensional model begun by Julie Schramm. This rewriting of the model has been done by MS student Louis Zuccarello, who will perform preliminary investigations of the solutions; this work will be continued by MS student Bruce Lambert.

Results:

The published methodology for using our composite stress fields in MABL updrafts and downdrafts (Sikora and Young 1994) provides the first-ever quantitative description of the planview patterns of air/sea flux of momentum; these patterns are suitable for forcing models of ocean waves and radar backscatter for the simulation of the kilometer-scale "mottled" convective signatures on SAR images such as those from ERS-I.

On a somewhat larger scale, preliminary theoretical analysis suggests that a solenoidal circulation, dynamically akin to the classic sea-breeze circulation, causes the significant MABL wind variations observed in the vicinity of the northwest wall of the Gulf Stream. This common phenomenon is often revealed by a cloud line in meteorological satellite and HIGH-RES cruise observations as well as by the band of altered wind direction in the MM4 mesoscale model forecasts and the RV Vernadsky transect. Further analysis of observations from the second HIGH-RES ARI cruise and quantitative diagnostics of the MM4 results are underway to complete the description of this phenomenon, its effect on the sea-surface stress field, and the range of conditions under which it can occur.

Theoretical understanding of possible kilometer-scale stratocumulus–topped boundary layer responses also increased. The key result of this work (Laufersweiler 1993; Laufersweiler and Shirer, 1994a,b) is that for the same thermal forcing rates (air-sea temperature differences and cloud base layer stabilities), the boundary layer circulation may adopt one of two possible

responses. The first response is a steady one that is partitioned into two cells, one in the subcloud layer and the other in the cloud layer; this response represents one hypothetical decoupled boundary layer configuration. The second response is a temporally periodic one that during its first part represents a circulation that is restricted to the subcloud layer and during its second part represents a circulation that penetrates into the cloud layer before collapsing back to the subcloud layer. This second response represents a boundary layer in which the subcloud layer and cloud layer periodically decouple and couple.

Development of an improved tool for estimating the correlation dimension and its probable error was completed as a Penn State Mathematics Department report (Wells *et al.* 1993); however, the version submitted to *Physica D* required extensive revision, which is being performed as part of our MBL ARI study (Wells *et al.*, 1994). This algorithm was applied to boundary layer wind observations by Fosmire (1993) and is now ready to be applied to other modeled and observed MABL datasets.

Accomplishments:

A new graduate student (Sean Sublette) is analyzing mesoscale model output in conjunction with HIGH-RES cruise observations to develop a composite description of the flow and stress fields associated with the MABL solenoidal circulation that is forced by the Gulf Stream ocean front. Theoretical insight into this frequently occurring phenomenon has been provided to interested ARI investigators, Don Thompson and Farid Askari. Also, George Young directed ship traverses of this phenomenon during the second HIGH-RES cruise. A strong sea surface roughness boundary associated with the Gulf Stream atmospheric front was located via real-time meteorological analysis of the atmospheric meso-circulation. Graduate students Peter Bromfield, Louis Zuccarello and Bruce Lambert are developing two- and three-dimensional models of the stress variability caused by MABL kilometer-scale circulations; these models are extensions of the first version coded by research associate Julie Schramm. PhD student Mark Laufersweiler completed his dissertation and graduated at the end of the Fall '93 semester. He has begun writing the version of his thesis work that will be submitted to the *Journal of the Atmospheric Sciences* (Laufersweiler and Shirer 1994b) and he will present this work at the AMS Eighth Conference on Atmospheric Radiation in January 1994 (Laufersweiler and Shirer 1994a). Finally, Christian Fosmire completed his MS thesis (Fosmire 1993) in which he applied the Wells *et al.* (1993, 1994) algorithm to boundary layer wind data.

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92-R Sikora, T.D., Air/sea flux patterns within convective structures of the marine atmospheric surface layer, MS Thesis, Penn State University, (1992) 28 pp.

92-C, 92-R Sikora, T.D and G.S. Young, Air/sea flux patterns within convective structures of the marine atmospheric surface layer, Preprints, *Tenth Symposium on Turbulence and Diffusion*, Sept. 29-Oct. 2, 1992, Portland, OR, American Meteorological Society (1992) 25-27.

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93-R Fosmire, C.J., Estimating the correlation dimension of observed boundary layer winds. MS Thesis, Penn State University (1993) 112 pp. .

93-PI Laufersweiler, M.J. and H.N. Shirer, A theoretical model of multi-regime convection in a stratocumulus-topped boundary layer (1994).

93-P Sikora, T.D. and G.S. Young, Observations of planview flux patterns within convective structures of the marine atmospheric surface layer, *Boundary Layer Meteorology* **65** (1993) 273-288.

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